SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

August 1990
NSRP 0320

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1990 Ship Production Symposium

Paper No. 5A-2: Computerized Angle Measurement for Inclining Experiments

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1990**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
The National Shipbuilding Research Program, 1990 Ship Production Symposium, Paper No. 5A-2: Computerized Angle Measurement for Inclining Experiments

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center CD Code 2230-Design Integration Tools Bldg 192, Room 128 9500 MacArthur Blvd, Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**10**	

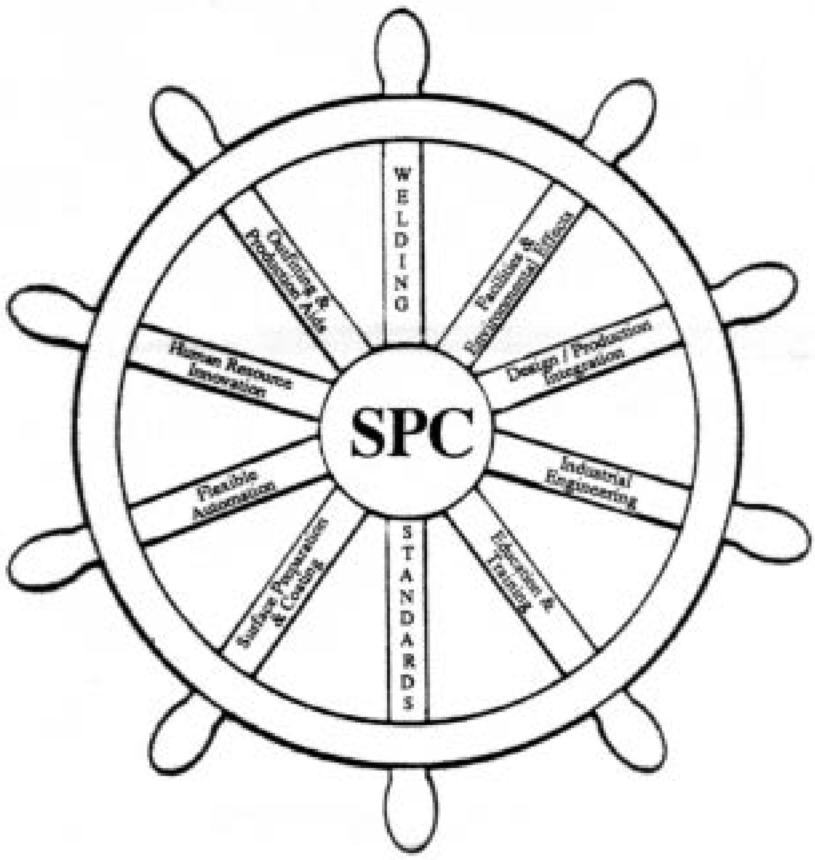
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM'S

1990 SHIP PRODUCTION SYMPOSIUM

Preparing for the 21st Century: Focusing on Productivity and Quality Management



August 22-24, 1990
Pfister Hotel
Milwaukee, Wisconsin

SPONSORED BY THE SHIP PRODUCTION COMMITTEE
AND HOSTED BY THE GREAT LAKES AND RIVERS SECTION OF
THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

S. N. A. M. E.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,199O

Computerized Angle Measurement for Inclining Experiments

5A-2

Victor Y. Chen, Member, **Peter K. Weinrich,** Member, JHH, Inc., Portsmouth, VA

ABSTRACT

This paper examines the application of the latest in precision electronic angle measurement instrumentation, combined with portable computer technology, to the measurement of the angles of inclination during inclining experiments. The Computerized Angle Measurement System (CAMS), developed by JJH Inc., will be described as to its configuration and function including the methods used in data acquisition to enhance both its ease of use and accuracy of the results. The software for data acquisition will also be discussed. The CAMS will be compared to traditional pendulums and mechanical tangent inclinometers in the areas of accuracy, cost, and ease of use. CAMS will be shown to be a very accurate, cost effective, and easy to use tool for angle measurement during inclining experiments.

INTRODUCTION

The stability characteristics of a vessel are always a main concern both during its design and throughout its service life. Maintaining adequate stability will ensure the vessel's ability to operate and to meet mission requirements. Inadequate stability will reduce the vessel's operating ability, cargo carrying capacity or could lead to disaster.

While much effort has been put forth in improving the techniques of weight estimating, weight reduction, weight control and weight accounting, during both the design and construction phases, the inclining experiment remains the only satisfactory method for determining the vertical center of gravity of a vessel either at the time of construction or throughout its service life. The inclining experiment provides the basic data for calculating the vessel's weight and centers of gravity in the vertical, longitudinal and transverse directions for use in all evaluations of stability.

During an inclining experiment, certified weights are placed onboard the vessel and shifted to create known transverse moments. The heel angles caused by these moments are accurately measured and their tangents are plotted against the moments to yield a straight line. The vessel's metacentric height (GM) is determined by dividing the slope of the plotted line by the vessel's displacement. A more detailed description of the inclining experiment stability test can be found in References [l] and [2].

Traditionally, the inclining angles have been measured by means of either pendulums or, in the case of many U. S. Navy ship inclinings, mechanical tangent inclinometers. More recently, electrical and electronic devices which display single angle measurements have occasionally been employed. Each of these devices is limited by either the time and expense involved in fabrication and assembly, the need for averaging the inclining angles "by eye", or the lack of a means for permanent data recording.

In order to overcome the limitations of these devices and to take advantage of some of the latest technology in precision electronic angle measurement instrumentation, the Computerized Angle Measurement System (CAMS) was developed.

CONFIGURATION OF THE CAMS

The CAMS consists of a laptop computer, three electronic clinometers, an RS232 serial communications multiplexer and a rechargeable battery. All of the components fit into two brief case size cases for easy transport. The general configuration of the CAMS is shown in Figure (1).

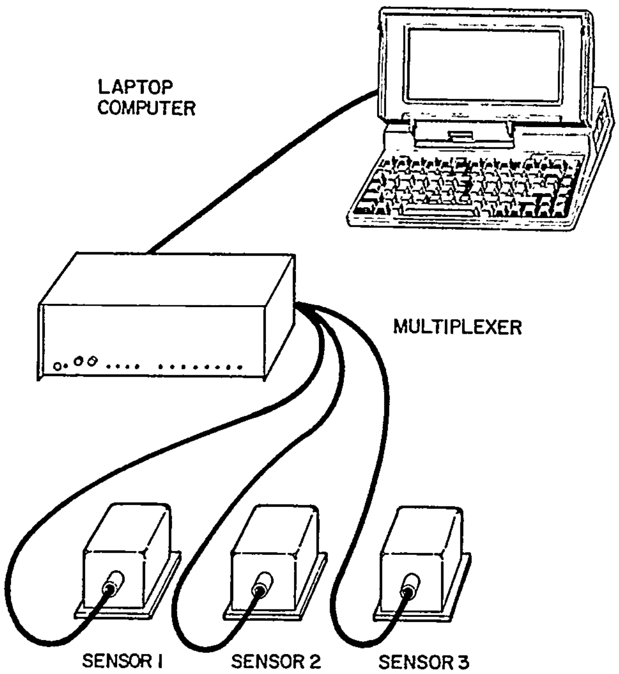


Fig. 1 Configuration of the CAMS

The brain of the system is the driving and controlling software written in BASIC Language and run by the laptop computer. The software is menu driven controlling RS232 serial communications, data acquisition, the saving of data to floppy disk, on-site data review and data printing. Figures (2) and (3) show the main menu and the readings menu. Not shown is the data review menu which has options identical to the readings menu in Figure (3). These three menus provide an overview of the various data acquisition and review options available. Single line prompts are provided for the other main menu options and keyboard inputs such as ship name, weights, and weight movement dimensions. An example of a printed report for a typical inclining is shown in Figure (4).

The system is set-up on a vessel with the laptop computer, the multiplexer and the battery in a weather protected area, usually the ship's bridge, with the clinometers placed as far apart as practical. Each clinometer must be placed on a smooth and solid part of the vessel's structure in locations where they will not be disturbed. The clinometers need not be located on perfectly level as will be explained later.

MAIN MENU

l-INITIALIZE DISK FOR NEW SHIP
2-CALIBRATION
3-TAKE READINGS
4-REVIEW READINGS FROM DISK
5-PRINT DATA TO PRINTER
6-TERMINATE SESSION
ENTER OPTION

Fig. 2 The Main Menu

************DATA RECORDING MENU************

l-INITIAL ZERO	10-1ST RECHECK STBD
2-1ST READING STBD	11-2ND RECHECK STBD
3-2ND READING STBD	12-3RD RECHECK STBD
4-3RD READING STBD	13-4TH RECHECK STBD
5-1ST ZERO RECHECK	14-3RD ZERO RECHECK
6-1ST READING PORT	15-1ST RECHECK PORT
7-2ND READING PORT	16-2ND RECHECK PORT
B-3RD READING PORT	17-3RD RECHECK PORT
9-2ND ZERO RECHECK	lB-4TH RECHECK PORT
M-MAIN MENU	

SELECT READING

Fig. 3 The Readings Menu

Each clinometer is housed in an all weather aluminum case, as shown in Figure (5), and is connected to the multiplexer via a 50 foot long cable with an all weather connector, allowing for remote placement. The 50 foot cable length was chosen as it is the maximum allowable length for accurate data transmission without the use of signal repeaters. The multiplexer is a four channel code activated switch which is connected to the RS232 communications port of the laptop computer via a three foot long cable. The multiplexer allows the single computer to switch between the three clinometers through use of software commands. Power for the computer is supplied by either an internal rechargeable battery or a 110 volt AC adapter. The electronic clinometers and the multiplexer are powered by the external rechargeable battery. The capability of operating under battery power was a requirement for all components as a portable system is desired.

********* CAMS INCLINING REPORT *********

SHIP: USS NEVERSAIL

DATE OF INCLINING: 08-31-88

WEIGHTS:		
	1	1.71 Lt
	2	1.70 Lt
	3	1.74 Lt
	4	1.57 Lt
	5	1.30 Lt
	6	1.59 Lt

					SENSOR 1		SENSOR 2		SENSOR 3	
OBS	UT	#	DIST (ft)	MOMENT (ft-Lt)	ANGLE (deg)	TANGENT (-Stbd)	ANGLE (deg)	TANGENT (-Stbd)	ANGLE (deg)	TANGENT (-Stbd)
1				0	0.00	0.00000	0.00	0.00000	0.00	0.00000
2		1	16.0	27.4	-0.87	-0.01519	-0.90	-0.01571	-0.91	-0.01588
3		1	16.0							
		3	16.0							
		5	16.0	76.0	-2.28	-0.03981	-2.26	-0.03946	-2.27	-0.03964
4		3	16.0							
		5	16.0	48.6	-1.47	-0.02566	-1.47	-0.02566	-1.46	-0.02548
5				0	0.01	0.00017	0.02	0.00035	0.02	0.00035
6		2	16.0	27.2	0.80	0.01396	0.79	0.01379	0.77	0.01344
7		2	16.0							
		4	16.0							
		6	16.0	77.7	2.28	0.03981	2.30	0.04016	2.31	0.04034
		4	16.0							
		6	16.0	50.5	1.48	0.02584	1.50	0.02619	1.52	0.02654

Fig. 4 A Typical Printed Inclining Report

THE CLINOMETER

Within the clinometer case is a microprocessor, a Program Read Only Memory (PROM) computer chip and a sensing unit. The clinometer electronically converts a difference in capacitance into a measurement of angular position. When triggered, the clinometer's microprocessor runs the program (stored in the PROM) reading the difference in capacitance from the sensor and converting this difference into an angle output in the RS232 serial communications format. The sensor and its operation are described as follows:

"The sensor housing consists of two, cast zinc chamber halves with a common capacitor plate sandwiched between. The two sensor halves form electrical ground plates equidistant from the common capacitor plate that isolates them. The capacitor is a copper-plated plastic disc, which has been chemically etched to create two, independent, capacitor plates. A partition in each sensor half electrically isolates the plates, thus forming two chambers in each sensor half. Each chamber is filled with equal amounts (by volume) of a dielectric liquid and an inert gas. Slots at the top and bottom of the partition permit equalization of the fluid level and gas pressure between the chambers.

"When the unit is rotated about its sensitive axis, the liquid and gas within the chambers move with respect to the two common capacitance plates. The liquid has a greater dielectric constant than the gas, so if one common plate is submerged more than the other, it will exhibit higher capacitance. Because of the constant radius (circular) shape, equal amounts of the capacitor plates will be covered/uncovered by the fluid as the sensor rotates. This assures a linear change in capacitance ratio and thus in output signal.

"The clinometer contains integral electronic circuitry to translate the sensor's differential capacitance into a usable output signa1[3]." The shape of the capacitance plate is precisely computer generated and a fluid mixture with an exact dielectric constant, conductivity, and viscosity is used to produce the linearity and resolution shown in Table I. Figure (6) shows the configuration of the sensor housing and capacitor plate.

TABLE I

CLINOMETER SPECIFICATIONS

Linearity	0 to 20 Deg	±0.05 Deg
	20 to 60 Deg	±0.1 Deg
Resolution	±0.001 Deg	
Range	±0 to 60 Deg	

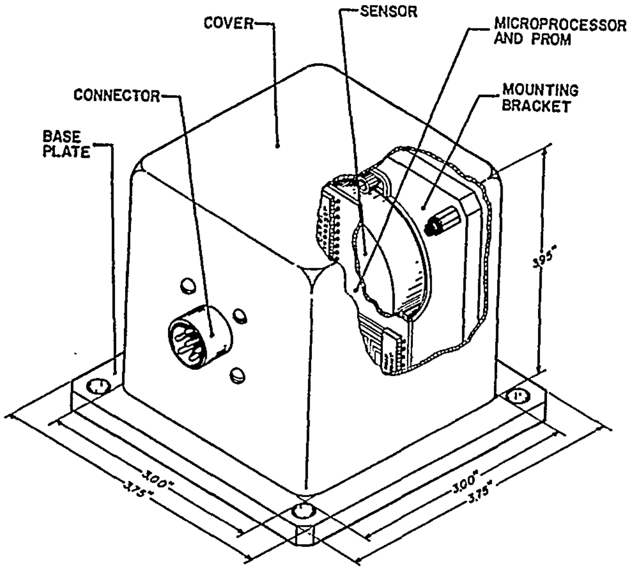


Fig. 5 The Clinometer

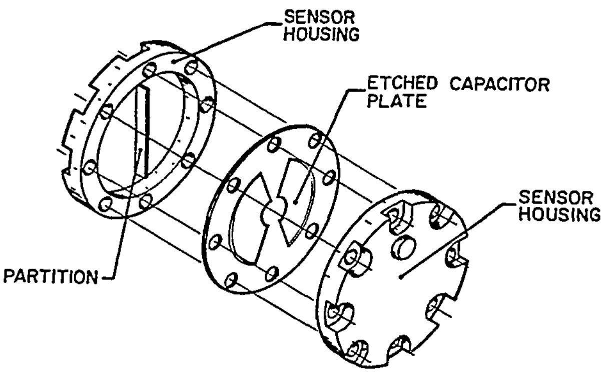


Fig. 6 Exploded View of the Sensor Housing and Capacitor Plate

CALIBRATION

Prior to an inclining experiment the clinometers must be calibrated. This is accomplished by placing the clinometer on a level surface and adjusting an internal zero pot until the clinometer reads zero degrees. Next, a calibration block is placed beneath the clinometer and an internal scale pot is adjusted until the clinometer reads the known angle of the calibration block. The calibration block is then rotated 180 degrees and the clinometer reading is checked to ensure consistency between port and starboard readings. Two calibration blocks have been fabricated, with 2 degree and 5 degree angles, for additional verification of the linearity of the scale adjustment.

Both the *zero* pot and the scale pot are located inside the clinometer's protective case which must be removed for access. The calibration is, therefore, performed in the office rather than on-site. This has proven *to be* quite satisfactory. Once the clinometers have been properly calibrated, no drift has been found in either the zero or scale, even after repeated calibration checks over a period of several months. Even though adjustments may not have to be made, the calibration is checked prior to use on each experiment.

A sub-routine in the computer program is provided for this calibration. With this routine the clinometer to be calibrated is selected and triggered repeatedly. The individual angle readings are displayed on the computer screen allowing for feedback as the zero pot or scale pot are adjusted.

DATA ACQUISITION METHODS

All data acquisition is controlled by the laptop computer running the menu driven computer program. The program provides and controls all channel selection signals to the multiplexer and trigger signals to the clinometers. The program sequences the proper signals to the multiplexer and the clinometers to facilitate the reading of the sensors in as simultaneous a manner as possible. The program also times the trigger signals to the clinometers to ensure triggering of each clinometer's internal sensor reading routine at the optimum frequency.

The sequencing of the program is as follows:

1. Channel 1, for clinometer 1, is selected.
2. Ten individual readings are taken.
3. Checks are made on the individual readings so erroneous data is disregarded. The acceptable data is then averaged.
4. Channel 2, for clinometer 2, is selected.
5. Ten readings are taken, checked and averaged.
6. Channel 3, for clinometer 3, is selected.
7. Ten readings are taken, checked and averaged.
8. Reiterate starting at Step 1.

After five iterations of this loop the five readings are averaged, the inclining angle reading is established and is displayed on the computer screen and saved to the floppy disk.

At the start of an inclining experiment an initial reading is taken at a condition of zero inclining moment. This reading is then used to compute the change in angle, and its tangent, for subsequent readings in the various heeled conditions. Using this method precludes the necessity for adjusting the clinometers to read a zero angle or to be placed on level structures.

COMPARISONS WITH OTHER EQUIPMENT

Pendulums

A typical pendulum arrangement is shown in Figure (7). Three such assemblies must be fabricated and then installed on the vessel at a considerable expenditure of man-hours. It is often difficult to find suitable locations for pendulums which must have a length of 10 feet or more in order to produce the 6 inch minimum deflection at maximum moment required by Reference [2]. This is especially difficult on smaller vessels. Many times the only suitable locations on any vessel are narrow vertical trunks making access for the pendulum reader and providing adequate lighting difficult. Installation and removal of the damping oil is also complicated by tight spaces. Access for accurate measurement of the pendulum length can be hampered by the pendulum being suspended under a hatch. Communication must also be provided between the three pendulum readers and the inclining supervisor.

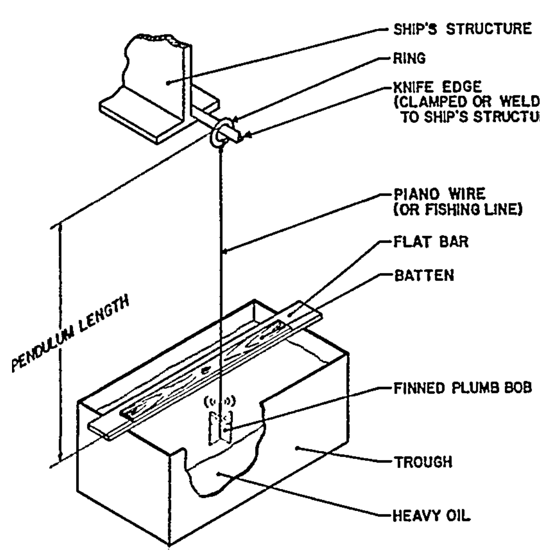


Fig. 7 A Typical Pendulum Assembly

The accuracy of a pendulum reading is largely dependent on the reader's experience and ability to average the pendulum's swing "by eye" and pick the mean of the swing to mark as the reading. There are also errors associated with measurement of the pendulum length and the marked deflection.

The CAMS requires very little time, effort or space for set-up. No vertical trunks are required and the computer can be set up next to the tangent plot table allowing one person to take all of the angle readings and construct the plot of tangents. A minimum of four personnel are required to perform these functions when pendulums are used. Pendulums must be set-up the day before the inclining by several people taking much of the day and inhibiting shin's force in their activities. Set-up on the CAMS requires only about 30 minutes of one person's time on the day of the inclining. The CAMS saves all of the angle readings along with data for weights and their movements while the only permanent record provided by a pendulum are deflection marks on the batten which make up only half of each reading.

Tangent Inclinometers

Figure (8) shows the configuration of a typical mechanical tangent inclinometer. These devices were developed by the U. S. Navy in the 1940's and have been used predominantly for the inclining of U. S. Navy ships. The tangent inclinometer is essentially a short (usually 10 inches long), horizontal pendulum. Three large radius spirit vials are used to establish level for the instrument. Three different radii are provided for coarse and fine adjustment. The unit is placed on a sturdy table or solid structure on the ship and is leveled for the initial zero reading by means of two screw feet. For each heel angle during the inclining, the top plate is re-leveled by using the graduated wheel at the right which turns a threaded rod through the top plate. The left end of the top plate acts as a pivot. The reading is the tangent of the angle and is determined from the position of the graduated wheel in relation to the vertical scale after re-leveling. An accuracy similar to that of a pendulum is achieved through holding very close tolerances in the machining of the various metal parts.

It is these close tolerances that cause the cost of building one tangent inclinometer to exceed the cost of all of the components of the CAMS together. Three tangent inclinometers would be required for an inclining experiment. The tangent inclinometer also provides no means for direct recording of the angle data like the CAMS and each tangent inclinometer requires an experienced individual reader and communications like those required for pendulums.

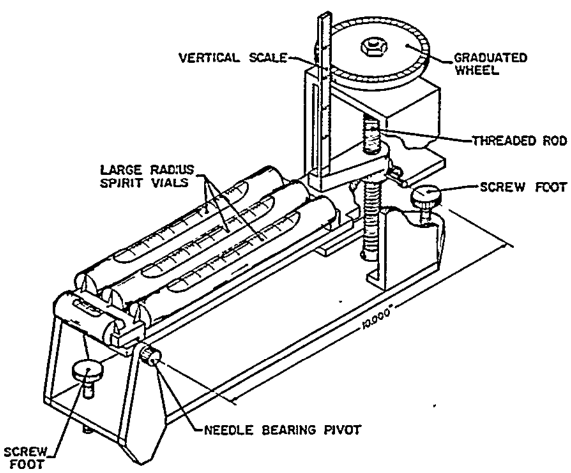


Fig. 8 A Typical Tangent Inclinometer

Other Electrical/Electronic Clinometers

Several electrical and electronic angle sensing devices were investigated during the development of the CAMS. The particular clinometer used in the CAMS was selected because it was the only device found which could provide for computerization of the system, direct saving of numerical values and portability through battery powering, all at a reasonable cost while providing a greater accuracy than any of the other devices considered.

CONCLUSIONS

The CAMS is a very accurate, cost effective, and easy to use angle measurement tool for inclining experiments. It is easier, cleaner and less expensive to install and more portable than pendulums. It also takes less manpower to use and provides for more complete and permanent data recording than either pendulums or tangent inclinometers. The CAMS has been used during inclining experiments on several U. S. Navy ships under the cognizance of the Naval Sea Systems Command (NAVSEA). With CAMS, the inclining experiment has entered the computer age.

REFERENCES

[1] Naval Ships' Technical Manual, Chapter 096, "Weights and Stability," 1977.

[2] United States Coast Guard, Navigation and Vessel Inspection Circular, No. NVC15-81, "Guidelines for Conducting Stability Tests." 1981.

[3] McCarty, Lyle H., Capacitance Difference Reveals Angular Position, Design News, June 1986.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

Documentation Center
The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

Phone: 734-763-2465
Fax: 734-763-4862
E-mail: Doc.Center@umich.edu